6 ALTERNATE EVALUATION

6.1 INTRODUCTION

This section describes an alternate evaluation methodology for demonstrating acceptable containment sump performance relative to the requirements identified in Section 2.

6.1.1 BACKGROUND

In SECY-02-0057 (Reference 1), the NRC staff recommended the development of risk-informed approaches to the technical requirements specified in 10 CFR 50.46 (Reference 2), and related provisions, concerning LOCA acceptance criteria and evaluation models. In its March 31, 2003 SRM (Reference 5), the NRC Commissioners directed the staff to undertake rulemakings, one of which would develop a proposed rule to allow, as a voluntary alternative, a redefinition of design basis maximum break size. In a March 4, 2004 letter to NEI (Reference 3), the NRC staff opened the possibility for risk-informing portions of the evaluation process for addressing GSI-191 concerns:

> "…the NRC staff plans to discuss, in public meetings, the use of current or planned work to risk-inform Title 10, *Code of Federal Regulations* Section 50.46, "Acceptance criteria for emergency core cooling system for light-water nuclear power reactors," as a suitable technical basis for defining a spectrum of break sizes for debris generation and containment sump strainer performance."

Most recently in SRM SECY-04-037 (Reference 4), the NRC Commissioners directed the staff to develop a rulemaking package to risk-inform the requirements addressing large break loss-of-coolant accidents (LOCA). The Commission directed the staff to use the initiating event frequencies from the expert elicitation process, supported by historical data and fracture mechanics analysis and other relevant information, to guide the determination of an appropriate alternative break size.

An alternate evaluation methodology for GSI-191 resolution is discussed in this section that builds on applicable risk insights from the preparatory work that supports risk informing the large break LOCA requirements.

6.1.2 OVERVIEW OF ALTERNATE EVALUATION METHODOLODGY

The alternate evaluation methodology (Option B of Figure 2-1) allows for use of an alternate break size in analyses of containment recirculation performance.

Implementation of the alternate evaluation methodology involves two separate analysis steps:

1) Region I – For pipe breaks up to an alternate break size, analyses of the containment sump performance use highly conservative analysis methodologies as described in Section 6.3.
2) Region II – For pipe breaks larger than the alternate break sizes, analyses of the containment sump performance use risk insights and more realistic analysis methodologies as described in Section 6.4.

The Region I and Region II nomenclature was chosen to provide a clean definition of the two analyses that would not be misinterpreted with other regulatory terminology and has no other significance.

The analysis for Region I is performed in the same manner as that described in Sections 3, 4 and 5 of this document with the exception that the maximum break size considered in the recirculation performance analysis is limited to an alternate break size that is less than the double-ended rupture of the largest pipe in the reactor coolant system. Section 6.3 provides additional guidance on the Region I analyses.

In implementing the alternate evaluation approach, it is necessary to demonstrate that reasonable assurance of mitigation capability is retained for break sizes between the alternate break size and the double-ended guillotine break of the largest pipe in the reactor coolant system. This is termed Region II and Section 6.4 provides guidance on appropriate analysis methods and assumptions. This Region II recirculation performance analysis is performed using more realistic analysis methods and assumptions.

The alternate methodology calls for a risk impact calculation to be performed when changes to the existing facility design are necessary to meet the acceptance criteria using the alternate methodologies described in this section. The risk impact calculation is used to assure that the changes to the facility design have sufficient reliability to provide reasonable assurance that they will perform their intended function. This risk calculation only applies for cases where active components and/or operator actions are considered and reliability can be measured. The risk impact is not calculated for passive components since they typically can be assumed to perform their function with a high degree of reliability based on design margins, etc. In cases where a measurable and inspectable reliability can be ascribed to a passive component, the risk assessment may be applicable.

6.2 ALTERNATE BREAK SIZE

In SRM-SECY-04-0037, the NRC Commissioners directed the NRC staff to use the initiating event frequencies from the expert elicitation process, supported by historical data and fracture mechanics analysis and other relevant information, to guide the determination of an appropriate alternative break size for the proposed large Break LOCA re-definition (also known as the proposed 50.46 rulemaking).

The preliminary results of the NRC's break size frequency expert elicitation process, as documented in SECY-04-0060 (Reference 6), has provided a new estimate of the probability of break flows over a wide range of possible pipe configurations. This expert elicitation process includes both probabilistic fracture mechanics considerations as well as margins for uncertainties concerning aging mechanisms and their impact on piping integrity. Of particular importance for PWRs, the expert elicitation gave strong weight to reactor vessel penetration integrity for the large break sizes and to steam generator tube failures for small break sizes. They also gave strong weighting to breaks in locations that have Alloy 600 welds based on operating experience. These locations are considered to be more probable than a circumferential break in a smooth piping segment. For these reasons, consideration of piping break size and break location will ideally be considered together in defining the Alternate Break Size. For example, considerations that led to the preliminary expert elicitation results indicate that the large break frequencies are dominated by reactor vessel penetration failures. Consideration of the debris generation and transport features of reactor vessel insulation indicates that these breaks do not generate significant debris that can be transported to the containment sump. Thus, the use of the expert elicitation in defining the alternate break size for sump performance assessments contains an inherent bias that provides added margin to the sump performance assessments.

The NRC Commissioners also provided clarification to the NRC staff with respect to the break size designation for the large break LOCA redefinition:

"For example, a frequency of 1 occurrence in 100,000 reactor years is an appropriate mean value for the LOCA frequency guideline for selecting the maximum design-basis LOCA since it is complemented by the requirement that appropriate mitigation capabilities, including effective severe accident mitigation strategies, must be retained for the beyond design-basis LOCA category."

Based on the preliminary break frequencies from the expert elicitation, this corresponds to about a 4 inch diameter break size.

To reflect the preliminary nature of the expert elicitation results and the need to resolve GSI-191 in a time frame that is much shorter than the proposed 50.46 rulemaking, a more deterministic alternate break size is used that will, with a high degree of certainty, bound the eventual break size that is specified in the post-rulemaking 50.46. In other words, the alternate break size uses insights from the proposed risk informed large break redefinition effort. In using this GSI-191 alternate break size, it is recognized that when the 50.46 rule is finalized, licensees can re-perform the sump performance evaluations with the final break size specified in 50.46 and modify the plant design and operation. This would assure coherence in the implementation of 50.46.

The alternate break size for the alternate evaluation of sump performance is defined as:

- A complete guillotine break of the largest line connected to the reactor coolant system loop piping. If sufficient energy for debris generation exists on both sides of the break, a double ended break will be used. For example the guillotine break of the pressurizer surge line would result in high pressure blowdown from both sides of the guillotine break location. However, in the case of a safety injection discharge line, amount of high pressure fluid in the pipe between the main loop piping and the first isolation valve is very limited and would not be expected to result in significant debris generation from the discharge from that side of the break.

  A criteria to be used to determine if a pipe has sufficient energy on both sides of the break to cause significant debris generation is 10 pipe inside diameters for large bore piping (i.e., greater than 2 inch diameter) and 20 pipe diameters for small bore piping. For example, consider a 14 inch diameter schedule 160 pipe (11.18 inch I.D.) connected to the main loop piping. If a normally closed isolation valve is within 9.3 feet (10 pipe diameters based on I.D.), then only a single ended break needs to be considered. This is based on the low stored energy in the pipe section between the break and isolation valve with respect to significant debris generation.

- For main loop piping, a break size will be assumed to be that equivalent to a guillotine break of a 14 inch schedule 160 line. A guillotine break of this pipe, with an ID of 11.19 inches, gives an effective break area of 196.6 square inches (assuming both sides of the break are pressurized). This is roughly equivalent to a single sided break of a 20 inch schedule 160 pipe with an ID of 16.06 inches.

In defining these break sizes, the alternate break size to be considered by each licensee for lines connected to the main loop piping is plant dependent, while the alternate break size to be applied to the main loop piping is identical for each licensee.

6.3 Region I Analysis

The analysis of recirculation system performance under the alternate evaluation process is performed in the same manner as described in Sections 3, 4 and 5 of this document, except that the maximum size of reactor coolant system (RCS) breaks to be considered is set by the "Alternate Break Size." The range of secondary side break sizes (e.g., steam line and feed line breaks) that will be considered is unchanged under the alternate evaluation methodology.

6.3.1 Break Size

For the Region I analysis a break size equal to or smaller than the alternate break size will be used as described in Section 6.2.

6.3.2 Break Location

The use of an alternate break size has no impact on the range of break locations to be considered. As discussed in Section 3, a full range of break locations will be assessed to determine the limiting location considering both debris generation and debris transport. However, Section 4 identifies that Branch Technical Position MEB 3-1 (Reference 7) may be used to limit the break locations considered. The use of an alternate break size could impact the limiting location of the break compared to analyses performed under Option A. Under Option A, the limiting break location considers the location of maximum debris generation / transport from a double ended guillotine break of the largest loop piping. When assessing the more limited alternate break size under Option B, the break location that results in the maximum debris generation / transport may be different from that of a double ended guillotine break.

6.3.3 Break Configuration

The maximum break size to be considered for a given primary-side piping location is the minimum of either the alternate break size established in section 6.2 or the maximum attainable effective break area, as discussed below. Circumferential breaks will be assumed to result in pipe severance and separation amounting to at least one-diameter lateral displacement of the ruptured piping sections unless physically limited by piping restraints and supports, or other plant structural members that can be shown through analysis to limit pipe movement to less than one diameter lateral displacement. For pipes with a larger diameter than the maximum break size, the maximum attainable break area would be modeled as a partial pipe break with an area equivalent to the double ended rupture of a pipe with the same diameter as the alternate break size. The worst location of the break in terms of orientation around the break location must be considered.

For example, the transverse internal area of a 14” schedule 160 pipe is 98.32 sq. in. The maximum attainable effective break area for this pipe is 2 times this value, or 196.65 sq. in (assuming a source high-energy flow from both directions). This break area would be applied to all main coolant loop piping.

6.3.4 Zone of Influence

The guidance in Section 3.4.2 on determination of the zone of influence for debris generation presumes a DEG break. For DEG breaks, a spherical Zone of Influence (ZOI) is conservatively postulated. This is appropriate for use in the alternate evaluation for breaks smaller than the alternate break size for piping connected to the main loop piping since a guillotine break of this piping is postulated. However for main loop piping, postulation of a break size less than the DEG break area would indicate a limited-displacement circumferential break or a longitudinal break, i.e., “split break”. This difference can be accounted for in one of the following ways:

- ZOI Based on a Hemisphere. The zone of influence for longitudinal, or split breaks, can be simulated as a hemisphere with radius determined by the destruction pressure of the insulation that would be affected by the postulated break. As described in Section 3.4.2.2, the ZOI value used in a plant specific calculation depends upon the destruction pressure of the insulation in the region of the break. To use the hemispherical ZOI modeling, the break orientation needs to be simulated at various angles around the loop piping to determine maximum debris generation.

- ZOI Based on a Sphere. Because a worst-case break orientation can be difficult to determine, an alternative to assuming a hemispherical ZOI is to translate the hemispherical volume into an equivalent volume sphere.

Additional guidance is also provided in Section 4 for the use of the following refinements to the guidance given above:

1. The use of debris specific zones of influence, and,
2. The use of directed jets to evaluate damage to insulation and coatings

These refinements may be applied at the option of the user to reduce the zone of influence for consideration of debris generation. In particular, for coolant loop piping and a postulated break size less than the DEG break area, the use of a directed jet for debris generation may require the determination of a worst-case break orientation.

6.3.5 Debris Generation, Transport and Accumulation

The guidance in Sections 3 and 4 is to be used to determine the debris generation (except for ZOI as discussed above), transport and accumulation on the containment sump screens for breaks smaller than the alternate break size.

6.3.6 Acceptance Criteria

The acceptance criteria for containment sump screen performance continues to be core cooling based on available NPSH equal to, or greater than, the required NPSH for all pumps required to operate for long term core cooling. The calculation of the required and available NPSH is based on the models and assumptions currently used in design basis analyses of sump and core cooling recirculation performance. In addition, if containment spray is credited in the design basis analyses (containment pressure, radiological consequence, etc.), the containment sump screen performance also includes NPSH margin for the operation of the minimum required containment spray.

6.3.7 Modifications to Event Timings and Conditions

Consideration will be given to the potential impact of the alternate break size on event timings, thermal/hydraulic conditions and NPSH requirements. Use of the alternate break size on either piping connected to the main loop piping or the main loop piping itself, in lieu of a full DEG break on the main loop piping, will affect key scenario events such as (but not limited to):

- the timing of transfer to recirculation from RWST injection,
- the containment sump water properties (e.g., temperature), and
- containment back-pressure (if credited in design basis analyses).

The evaluation will consider these revised timings as appropriate.

6.3.8 Operator Actions

The use of break sizes smaller than a full double-ended rupture may result in significant differences in the time at which core cooling recirculation would be initiated. The impact of operator actions to mitigate containment sump blockage may be considered for these scenarios provided that the operator actions meet the criterion for consideration in design basis analyses. These considerations would include adequate time for operator action per design basis "rules", proceduralized guidance, job-task-analysis, etc.

6.4 Region II Analysis

In implementing the alternate evaluation methodology (Option B) approach, reasonable assurance must be provided that mitigation capability is retained for break sizes between the alternate break size and a guillotine break of the largest main coolant loop pipe. This evaluation is performed using more realistic analysis methods and assumptions and credit can be taken for operation of non-safety systems, structures and components, as well as expected operator actions. In addition, modification of the acceptance criteria (i.e., NPSH considerations) applicable to design basis analyses is permitted. The list of potential modifications to the set of conservative methods and assumptions used in the design basis analysis can be large. To simplify the Region II analysis process the following sections identify a recommended set of modifications to methods and assumptions described in Section 3 through 5. These modifications were selected based on the potential for the largest benefits in terms of the use of more realistic models and assumptions that affect the analyzed containment sump performance (as opposed to the actual sump performance).

6.4.1 Break Size

Break sizes that need to be considered in the Region II analysis cover the range from "Alternate Break Size" identified in Section 6.2 up to a guillotine break of the loop piping.

6.4.2 Break Location

Primary side piping whose attainable break area is less than or equal to the "Alternate Break Size" will have already been addressed as part of the design basis analysis described in Section 6.3 and can be excluded from further consideration as part of the Region II analysis. Any postulated secondary side break locations will also have been addressed as part of the Region I analysis and can be excluded from the Region II analysis. Consequently, all high energy piping locations except for main loop piping are fully addressed as part of the design basis analysis. If a licensee chooses to use an alternate break size smaller than the largest connected piping to the main coolant loop, as discussed in Section 6.2, then connected piping larger than the alternate break size would be addressed as part of the Region II evaluation.

For the remaining break locations, guidance provided in Generic Letter 87-11, *Relaxation in Arbitrary Intermediate Pipe Rupture Requirements* (Reference 8) and the associated Branch Technical Position MEB 3-1, *Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment*, should be used to identify postulated primary side break locations. The use of MEB 3-1 to identify the break locations is within the design basis as discussed in the Background of that document:

> "This position on pipe rupture postulation is intended to comply with the requirements of General Design Criteria 4 of Appendix A to 10 CFR Part 50 for the design of nuclear power plant structures and components…The rules of this position are intended to utilize the available piping design information by postulating pipe ruptures at locations having relatively higher potential for failure, <u>such that an adequate and practical level of protection may be achieved</u> (emphasis added)."

As discussed in Section 6.2 and SECY-04-0060, the NRC's Option 3 expert elicitation gave strong weight to reactor vessel penetration integrity for the large break sizes and steam generator tube failures for small break sizes. They also gave strong weighting to breaks in locations that have Alloy 600 welds based on operating experience. These locations are considered to be more probable than a circumferential break in a smooth piping segment. For these reasons, consideration of piping break locations as defined in

MEB 3-1 are considered for breaks larger than the alternate break size. In the development of MEB 3-1, it was recognized that some pipe break locations were of sufficiently low probability that these locations did not require additional design considerations to limit their consequences. Consequently, MEB 3-1 identifies that the dynamic effects of pipe breaks need only be considered for high stress and fatigue pipe locations, such as at the terminal ends of a piping system at its connection to the nozzles of a component. Breaks at locations other than those prescribed by MEB 3-1 have been determined by the NRC staff to be of sufficiently low probability that the design need not accommodate their dynamic effects. The position taken in MEB 3-1 is confirmed by the NRC's Option 3 expert panel. Therefore, consideration of breaks in loop piping at locations identified in MEB 3-1 provides confidence that an adequate and practical level of protection is achieved.

6.4.3 Break Configuration

All breaks considered in the Region II evaluation are main coolant loop piping, except in the case where the licensee has defined the alternate break size as less than the largest pipe connected to the main coolant loop piping, as discussed in Section 6.2. In any case, the Region II evaluation does not consider partial breaks of piping. Partial breaks of main coolant loop piping (and other connected piping) have already been considered as part of the Region I evaluation, as discussed in Section 6.3. Partial breaks larger than the alternate break size are not considered in the Region II evaluation because the Region II evaluation already considers guillotine breaks in these pipes. Therefore, the Region II evaluation is limited to guillotine pipe breaks.

These circumferential breaks are assumed to result in pipe severance and separation amounting to at least one-diameter lateral displacement of the ruptured piping sections unless physically limited by piping restraints and supports, other plant structural members, or piping stiffness as may be demonstrated by analysis. Existing plant-specific dynamic loads analyses for postulated primary side breaks are utilized to assist the determination of the break configuration for the Region II analysis.

6.4.4 Zone of Influence

The guidance in Sections 3 and 4 and in Section 6.3.4 is used to determine the ZOI. There are a number of known conservatisms in the ZOI model presented in Sections 3 and 4. However, development of a technically sound model to more realistically model the ZOI, based on existing experimental and analytical data, is quite complex and has not been initiated due to the time constraints for development of the Region II guidance. Therefore, use of the ZOI evaluation methods in Sections 3 and 4 will be used for the Region II evaluation.

6.4.5 Debris Generation, Transport and Accumulation

The guidance in Sections 3 and 4 is used to determine the debris generation, transport and accumulation on the containment sump screens for Region II evaluations.

The current experimental and analytical basis for the generation, transport and accumulation does not easily lend itself to the quantification of more realistic models. The evaluations models presented in Sections 3 and 4 are considered to be bounding models to assure that the debris generation, transport and accumulation is not under-predicted. Thus, there are known conservatisms in each portion of the model evaluation models presented in Sections 3 and 4. However, development of more realistic models is difficult due to the limited amount of experimental and analytical information available for any single aspect of the model. This development work has not been initiated due to the time constraints for completion of the Region II guidance.

6.4.6 Acceptance Criteria

The acceptance criterion for containment sump screen performance is continued core and containment cooling. The applicable criteria to demonstrate retained mitigation capability for long-term cooling capability in the Region II analysis are:

1. Positive NPSH margin is maintained for the minimum number of ECCS pumps necessary to demonstrate adequate core cooling flow, and
2. Demonstration of adequate containment cooling capability to provide assurance that the containment boundary remains intact.

The first criterion (positive NPSH margin is maintained for the minimum number of ECCS pumps) can be met by ensuring NPSH margin is maintained for one or more moderate to high-capacity ECCS injection pumps (e.g., low-head RHR pumps for W-NSSS plants or either high-head or low-head SI pumps for CE NSSS plants. The calculation of the required and available NPSH is discussed below in Section 6.4.7.

For the Region II evaluation, limited operation without NPSH margin is acceptable if it can be shown that the pumps can reasonably be expected to survive during the time period of inadequate available NPSH. For example, if vendor information for a pump identifies that operation in a cavitation model for a limited period of time would not be expected to harm the long term pump performance, this may be considered in the Region II evaluation. In crediting pump operation under inadequate available NPSH conditions, it is recognized that both the time of operation with inadequate available NPSH and the magnitude of the inadequate available NPSH need to be considered. Vendor information may be used to justify continued pump operation under episodes of inadequate available NPSH. The vendor information may be test data or engineering judgment derived from tests and/or operational events.

For plants relying on decay heat removal via modes other than the minimum ECC recirculation pathway that meets the first criterion would also have to assure that the heat removal pathway is also available. For example, some plants require containment spray recirculation for decay heat removal (e.g., subatmospheric containment plants and some CE NSSS plants). In this case, some containment spray flow would have to be maintained as discussed in Criterion 2.

The second criterion (demonstration of adequate containment cooling capability) can be met through credit taken for minimal heat-removal pathways, including containment fan coolers, permitted by emergency procedures. Subatmospheric containment plants would not have to demonstrate that the containment remains below atmospheric pressure for the duration of the accident, if permitted by the emergency procedures.

In addition, exceeding nominal transient containment design pressure/temperature and EQ envelopes is allowed for Region II analysis, if reasonable assurance is provided that containment pressure boundary failure or vital equipment failure would not be expected to occur.

6.4.7 Net Positive Suction Head Calculation

Use of an alternate NPSH calculation, in lieu of the conservative calculation method prescribed by Regulatory Guide 1.1, “Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal System Pumps” (Reference 9), and Regulatory Guide 1.82, Rev. 3, “Water Sources for Long-Term Recirculation Cooling Following a Loss-Of-Coolant Accident”(Reference 10), is recommended for the evaluation of break sizes larger than the alternate break size. The conservative factors involved in the calculation of NPSH, including event timings, thermal/hydraulic conditions and plant physical configurations, may be evaluated to provide a more realistic calculation of NPSH available. This section discusses the potential impact of factors that have a positive impact on more realistic analysis of available net positive suction head (NPSH).

In applying a more realistic NPSH calculation to the Region II evaluation, which is still within the plant design basis, it is recognized that operability assessments, for example, such as those identified in Generic Letter 91-18 (Reference 11), do not need to be undertaken when nominal parameters used in the assessment are exceeded for a short period of time (e.g., less than 30 days). The NPSH margin still available, even using these more realistic analysis models, combined with the short time period of exceedance of the values used in this analysis and the low probability of a break larger than the alternate break size support continued operation without an operability assessment under these conditions.

6.4.7.1 NPSH Available

The Hydraulic Institute Standard ANSI/HI 1.1-1.5-1994 (Reference 12), defines NPSH as the total suction head in feet absolute, determined at the suction nozzle and corrected to datum, less the vapor pressure of the liquid in feet absolute. It is an analysis of energy conditions on the suction side of a pump to determine if the liquid will vaporize at the lowest pressure point in the pump. The typical equation governing the calculation of available NPSH is given as:

$$NPSH_A = H_P + H_{El} - H_{VP} – H_F$$

Where:

H_P = absolute pressure head at the pump suction pressure
= $(P_{gage}) \times \rho/144 in^2/ft^2$
ρ = fluid density (lbs/ft^3)
H_{El} = Elevation head
H_{VP} = Vapor pressure at prevailing water temperature converted to head
= $(P_{vapor})\ \rho/144 in^2/ft^2$
H_F = form and frictional head losses including through the sump screen, entrance losses and piping losses

Each of the contributing factors to the available NPSH are typically calculated based on conservative assumptions to assure that adequate NPSH is available under all a wide range of possible conditions. Calculation of available NPSH based on more realistic basis may be used to demonstrate that adequate margin exists between available and required NPSH. The following discussion evaluates each of the above contributors, plant status and thermal hydraulic conditions that will effect the calculation of available NPSH and to a lesser extent the NPSH required.

Suction Elevation Head

This parameter is the flooded level within containment above the pump suction centerline. Historically the value has been calculated based on absolute minimum values of water delivered to the containment sump.   Considerations to provide a more accurate estimate of sump levels should include the following:

- The nominal operating volume in the RWST and the accumulators are to be utilized rather than the Technical Specification minimum values,.
- RWST and accumulator volume delivered to the containment do not include instrument error volumes that are typically considered in determining a conservative delivered sump volume.
- The volume of water estimated to be delivered to the containment as the switchover of safety injection and containment spray pumps are manually (or automatically) completed are to be used rather than the RWST volume delivered at the ECC switchover setpoint based on RWST level
- Containment sump inventory is to include RCS volumes that will be in the containment sump post accident. Since only breaks larger than the alternate break size are considered in this portion of the alternate evaluation methodology, it is not expected that the RCS would be refilled. Analyses performed for W-NSSS plants to determine the minimum break size for consideration of switchover to hot leg recirculation to prevent boron buildup in the reactor vessel concluded that the RCS could not be refilled for breaks larger than 10 inches equivalent diameter. Therefore it is appropriate to include the primary side of the steam generators, the pressurizer and surge line, and the vessel head volumes in the containment sump water inventory available at the beginning of ECC recirculation.
- Best estimate holdup volumes within the containment are to be used.

Absolute Pressure Head and Vapor Pressure Head

This parameter is the head that can be attributed to the pressure exerted on the fluid in the sump by external forces. Typically for PWRs that do not credit containment overpressure in the design basis analyses, the basic assumption is to conservatively assume that containment pressure equals the vapor pressure of the liquid in the sump. In reality, this assumes that there is no air partial pressure in containment prior to the event, or that the air pressure is non-mechanistically lost during the event. A more realistic assumption is that at the time of safety injection recirculation the containment partial steam pressure is equal to sump fluid vapor pressure plus an air partial pressure equal to the containment air pressure prior to the event. The air pressure prior to the event is to be calculated assuming 100% relative humidity at a containment temperature corresponding to the maximum normal temperature experienced at the plant. Alternatively, the pre-event minimum containment pressure minus the partial steam pressure at the dew point temperature for the cooling water temperature can be assumed for the air pressure. The recognition of the pre-event air pressure acknowledges the thermal-hydraulic condition of containment prior to the event without crediting containment overpressure based on the accident scenario.

Regulatory Guide 1.82 specifies that ECC and containment heat removal systems should be designed so that sufficient available NPSH is provided to the system pumps, assuming the maximum expected temperature of pumped fluid and no increase in containment pressure from that present prior to the postulated LOCA. Further, RG 1.82 acknowledges that for cases where the design cannot be practicably altered, conformance with the above regulatory position may not be possible. In these cases, additional containment pressure may be included in the determination of available NPSH, but only to the extent that is necessary to preclude calculated pump cavitation. This allowance acknowledges that the calculation of available containment pressure and sump water temperature as a function of time will underestimate the expected containment pressure and overestimate the sump water temperature when determining available NPSH for this situation. Elevated containment pressure is to be credited in the alternate evaluation methodology only after full consideration has been given to other possible use of more realistic models and assumptions in the analysis.

When credit for containment pressure above atmospheric pressure is included in the NPSH available evaluation, a new containment analysis is likely to be required since the calculation for ECC backpressure typically only considers the first few minutes of the accident scenario. The following considerations will be assessed to assure that a conservatively low containment overpressure is credited:

- The use of the nominal RWST temperature and nominal containment pressure and temperature based on operating experience.
- A slower rate of release of stored thermal energy from the steam generators to the containment environment may be considered. For example, a steam generator stored thermal energy release rate over the first two hours of the postulated event may be considered.
- Realistic containment heat removal, both active and passive, may be assumed.
- Other input parameters to the LOCA mass & energy containment integrity analysis should be reviewed to identify those parameters that may be changed to calculate a nominal containment overpressure.

Friction and Form Head Loss

This parameter is the sum of the head losses through the containment sump screen, containment sump and suction piping. The head losses through the sump screen are the subject of Sections 3.2.5 and 4.2.5. The guidance of those sections is to be followed in the head loss determination. A refinement to this approach may be considered based on realistic conditions for the fluid approach velocity in the sump screen head loss calculations. Two examples of more realistic conditions are:

- At switchover to ECC recirculation, the containment spray pumps typically remain aligned to the RWST until the entire usable RWST inventory is drained to the containment. Thus, the fluid approach velocity at the beginning of ECC recirculation will only consider the pumps taking suction from the containment sump at that time. A second calculation may be required to determine the head loss with containment spray pumps taking suction from the containment sump, if applicable (see Section 6.4.9 on Operator Actions). However, that second calculation may also consider the increased elevation head available due to draining the entire usable RWST to the containment sump.
- In response to NRC Bulletin 2003-1 (Reference 13), a set of compensatory measures were identified and additional generic Emergency Response Guideline procedures and/or procedure steps were developed. Credit for these operator actions to reduce the approach velocity may be taken where those procedures

have been implemented. More information on credit for operator actions can be found in Section 6.4.9.

Friction and form losses calculated for entrance losses into the sump (exclusive of the screen) and in the pump suction piping are normally calculated using standardized loss factors from generally accepted handbook sources such as Crane Technical Paper 410, “Flow of Fluids” (Reference 14). Experience has shown that these calculations are typically conservative (higher projected frictional and form losses) than field experience has shown. The magnitude of the conservatism for these handbooks is normally in the range of 15 to 25 percent. If handbook sources have been used to calculate the head losses input into the NPSH evaluation, then the values may be reduced to be more realistic, based on either engineering judgment or test results that provide evidence of the losses.

6.4.7.2 NPSH Required

The Hydraulics Institute defines NPSH required as “the amount of suction head, over vapor pressure, required to prevent more than 3% loss in total head from the first stage of the pump at a specific rate of flow”. Therefore, this value is indicative of when head loss begins to occur rather than when incipient pump damage occurs. In the containment sump recirculation mode, pump developed head is not necessarily a critical parameter and thus the pump vendor may able to provide relief in the amount of NPSH required to avoid pump damage rather than the established formal definition of required NPSH. However, tests have shown that there is typically very little margin between the NPSH at which 3% loss in total head occurs and the NPSH at which pump impeller damage occurs. While the margin is dependent on the pump design, it is generally quite small. This aspect of NPSH is not recommended for further investigation unless vendor information, derived from tests or operating experience, indicates that there are atypical margins available.

ANSI/ HI 1.1-1.5-1994 also specifies a method of accounting for the decrease in required NPSH with an increase in temperature of the pumped fluid. This method is subject to restrictions specified in the standard dealing with experience with the specific pump, the amount of air dissolved in the fluid, and the transient nature of the pressure and temperature of the pumped fluid. Therefore, it is recommended that credit not be taken for the reduction in required NPSH due to the temperature of the pumped fluid, because of the uncertainty in these factors.

6.4.7.3 Calculational Method

Credit for more realistic calculation of the available and required NPSH requires careful examination of the integrated time dependent changes in the parameters that can impact the available and required NPSH over the range of possible break sizes considered for the Region II evaluation methodology. The impact of the break size, from the alternate break size to a guillotine break, on the parameters that impact the available and required NPSH also need to be considered. The containment and sump responses (sump water level, sump screen approach velocity, sump water temperature and containment pressure) used in the NPSH assessments need to be carefully assessed to assure that the available NPSH is not underestimated and the required NPSH is not overestimated.
The single failure assumption used for design basis ECC performance analyses is generally not appropriate for containment sump performance calculations since the maximum sump approach velocities and minimum containment conditions will typically control the results.

The following assumptions are generally acceptable for the calculation of more realistic available and required NPSH:

- Containment water level consistent with nominal RWST and RCS volumes that would be expected to be in the containment sump for the break size under consideration and realistic assessment of holdup volumes.
- Containment sump temperatures based on realistic decay heat rates, as defined in ANSI 5.1 1979 (Reference 15) and nominal heat removal using maximum service water / component cooling water temperatures that represent at least the 95th percentile from operating experience.
- Containment pressure head based on absolute pressure rather than vapor pressure.
- If additional credit is taken for containment overpressure, an analysis that minimizes the containment pressure is to be performed to assure that the containment overpressure is not overestimated. Credit for containment overpressure should only be taken as a last resort where a design difference would be mandated without credit for overpressure.
- The sump screen approach velocity for the head loss calculation is to realistically consider the maximum pumps drawing from the sump as a function of time, including credit for appropriate operator actions to terminate operation of certain pumps.

- More realistic factors for head loss in the sump entrance (exclusive of the sump screens) and the suction piping may be used based on engineering judgment or test results.

6.4.8 Timing of Events

More realistic modeling of debris generation, transport and accumulation on sump screens can be considered based on the timing of debris generation, transport, and accumulation in relation to the timing of the available and required NPSH. The design basis analyses described in Sections 3 and 4 assume that the maximum debris is available on the sump screens and available NPSH requirements are the minimum that occur over the entire accident scenario. A more realistic assessment would take into account that:

- debris generation, transport and accumulation is time dependent,
- available NPSH is time dependent, and
- the maximum debris accumulation and the minimum required NPSH may not occur simultaneously.

Therefore, a time dependent treatment of debris accumulation and NPSH requirements will use the following guidelines:

- for the debris generation as a result of the pipe break, the debris is available for transport at the initiation of the accident,
- for debris generation as a result of containment spray and other latent sources, an arbitrary linear debris generation over a period of one hour will be assumed,
- for debris transport to the sump screens, the time is to be based on sump velocities as discussed in Sections 3 and 4,
- for the assessment of head loss at the sump screen, the time dependent flow through the screen is to be considered, including credit for operator actions to terminate one or more pumps taking suction from the sump, and
- for assessment of available NPSH, time dependent sump water properties (e.g., temperature, depth) are to be used.

6.4.9 Operator Actions

An important allowance in the Region II analysis is credit for operator actions and the operation of non-safety equipment.

The operator actions that can be credited include those directed by emergency procedures. In applying operator actions, an assessment of the accident sequences and procedures is necessary to assure that there is reasonable confidence that the operator actions can be effective. The operator actions may include some of the compensatory actions identified in licensee response to NRC Bulletin 2003-1, including:

- Termination or reduction of containment spray recirculation when it is not needed for containment cooling,
- Termination of excess ECC recirculation capability when it is not needed to long term core cooling,
- RCS cooldown and depressurization to use shutdown cooling in place of ECC recirculation, which may also involve establishing an alternate means of RCS (i.e., after the initial RWST volume is used).

The operations that can be credited will be plant-specific, but could include:

- Credit for non-safety active screens, screen backwash systems or similar modifications to containment sump screen design
- Credit for shutdown cooling and alternate methods of RWST makeup.

6.5 Risk Insights

In the event that plant specific changes to the plant design / operation are made to address the sump blockage issue, risk insights can be used to assure that the changes can reasonably be expected to provide adequate protection for a wide range of accidents. In particular, risk tools can be used to determine the targeted reliability of the changes. These risk insights need only be applied to plant modifications involving active components and /or operator actions that are made solely to show compliance with the acceptance criteria for alternate evaluations described in Section 6. The risk calculation does not apply to passive components (e.g., enlarged sump screen area) since they typically can be assumed to perform their function with a high degree of reliability based on design margins, etc. In cases where a measurable and inspectable reliability can be ascribed to a passive component (e.g., passive screen cleaning), the risk assessment may be applicable.

The minimum reliability for active components and operator actions is to be determined from the maximum acceptable change in risk (e.g., core damage frequency, or CDF) for a baseline risk value. A simplified generic risk assessment can be developed that provides a bounding targeted reliability of the modifications to provide reasonable assurance of adequate containment sump performance.

As a bounding assessment, the change in core damage frequency is modeled to be the product of the large break LOCA frequency and the probability that the mitigation feature fails:

Delta CDF = LBLOCA IEF * Mitigation FP

Where: Delta CDF is the change in CDF as a result of implementing the mitigation system
LBLOCA IEF is the large break LOCA initiating event frequency
Mitigation FP is the Mitigation System Failure Probability

This simplified calculation assumes:

- An idealized base case condition in which the sump does not clog if the mitigation operates
- A bounding alternate case where the sump will clog and core damage occurs if the mitigation system fails (e.g., CDF probability is 1.0)
- There is no credit for successful recovery actions if the mitigation system fails.

For the LBLOCA initiating event frequency, the value of 5.0 E-04 per reactor year that was used in NUREG-1150 (Reference 16) represents a generic bound that may be used in the assessment in place of plant specific values from the licensees PRA. The generic bounding value is not likely to be exceeded in future considerations of break size vs. frequency for the Option 3 large break LOCA redefinition effort. This assures that updates to this risk assessment will be unaffected by the final break frequency considerations used in Option 3.

The acceptable Delta CDF is derived from Regulatory Guide 1.174 (Reference 17). From Regulatory Guide 1.174, when the calculated increase in CDF is in the range of 1.0 E-06 per reactor year to 1.0 E-05 per reactor year, changes in the licensing basis are to be considered only if it can be reasonably shown that the total CDF is less than 1.0 E-04 per reactor year (Region II of Figure 3 of the Regulatory Guide). The CDF of less than 1.0 E-04 bounds the population of PWRs.

A simple bounding PRA logic can be defined where the failure of ECC recirculation is dominated by the failure of the modification considered for sump blockage mitigation. This would then be dominated by the mitigation equipment reliability, or the operator action credited for mitigation.

Using a bounding generic value for LBLOCA initiating event frequency of 5.0 E-04 per year as identified in NUREG-1150 and a minimum change in CDF as a result of the modification of 1.0 E-05 per year from Regulatory Guide 1.174, yields a required unreliability of 2.0 E-02 per demand. This can be translated to a targeted reliability of 98% per demand for operator actions and or active components.

This generic risk calculation does not need to be repeated for plant specific assessments. Plant specific assessments of proposed changes would only have to assure that a target reliability of 98% per demand could reasonably be met.

Establishing a combination of extremely low probability of needing containment sump recirculation and challenging the containment sump performance will provide suitable redundancy for the regulatory intent to be met by not assuming single failures of active components. Thus, the defense in depth and safety margin considerations in Regulatory Guide 1.174 can be implicitly assured by the low probabilities of the events.

6.6 REFERENCES

1. SECY-02-0057, "Update to SECY-01-0133, 'Fourth Status Report on Study of Risk Informed Changes to the Technical Requirements of 10 CFR Part 50 (Option 3) and Recommendation on Risk-Informed Changes to 10 CFR 50.46 (ECCS Acceptance Criteria)".

2. 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light Water Nuclear Power Reactors".

3. Letter from Suzanne C. Black, NRC, to Anthony Pietrangelo, NEI, "Nuclear Energy Institute's Proposals for Determining Limiting Pipe Break Size Used in

Assessing Debris Generation Following a Design Basis LOCA (TAC NO. MC1154," March 4, 2004.

4. SRM-SECY-04-0037, "Staff Requirements - SECY-04-0037 – Issues Related to Proposed Rulemaking to Risk-Inform Requirements Related to Large Break Loss-of-Coolant Accident (LOCA) Break Size and Plans for Rulemaking on LOCA with Coincident Loss-of-Offsite Power.

5. SRM-SECY-02-0057, "Staff Requirements - SECY-02-0057 – Update to SECY-01-0133, "Fourth Status Report on Study of Risk-Informed Changes to the Technical Requirements of 10 CFR PART 50 (Option 3) and Recommendations on Risk-Informed Changes to 10 CFR 50.46 (ECCS Acceptance Criteria)".

6. SECY-04-0060, "Loss-of Coolant Accident Break Frequencies for the Option III Risk-Informed Reevaluation of 10 CFR 50.46, Appendix K to 10 CFR Part 50, and General Design Criteria (GDC) 35.

7. Branch Technical Position MEB 3-1, Revision 2, "Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment".

8. Generic Letter 87-11, " Relaxation in Arbitrary Intermediate Pipe Rupture Requirements".

9. Regulatory Guide 1.1, "Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal System Pumps".

10. Regulatory Guide 1.82, Rev. 3, "Water Sources for Long-Term Recirculation Cooling Following a Loss-Of-Coolant Accident".

11. Generic Letter 91-18, Revision 1, "Information to Licensees Regarding NRC Inspection Manual on Resolution of Degraded and Nonconforming Conditions".

12. ANSI/HI 1.1-1.5 -1994, "Centrifugal Pumps - Nomenclature, Definitions, Applications And Operation".

13. NRC Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors," June 9, 2003.

14. Crane Technical Paper 410, “Flow of Fluids”.

15. ANSI/ANS 5.1-1979, “American National Standard for Decay Heat Power in Light Water Reactors”.

16. NUREG-1150, Volumes 1 and 2, “Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants”.

17. Regulatory Guide 1.174, “An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis”.